GEO/OC 103
Exploring the Deep…

Lab 7

Unit 4
Marine Productivity

In this unit, you will

- ***Discover patterns in global primary productivity.***
- ***Compare terrestrial and marine productivity.***
- ***Explore the key resources required for productivity.***
- ***Correlate variations in marine productivity with limiting resources.***
- ***Investigate sources of marine nutrients.***
- ***Synthesize observations to evaluate the causes of dead zones.***

NOAA

The ocean provides up to 20 percent of the world's food supply.

Warm-up 4.1

Bounty from the sea

Seafood makes up 20 percent of the world's food supply, with over one billion people depending on its resources for survival. As seafood harvests have increased over the past two centuries, populations of some species of marine life have decreased and even become extinct. Given the ocean's vast area, it is difficult to locate, monitor, and track changes in stocks of commercially important fish and shellfish. Thus, scientists frequently use satellites to indirectly assess the health of fisheries and the ocean ecosystem.

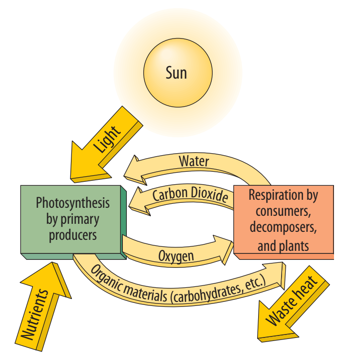


Figure 1. Photosynthesis and respiration.

A key indicator of the ocean's health is *primary productivity,* or the rate at which new organic material is produced through *photosynthesis* (Figure 1 at left). Photosynthesis is the process by which plant cells containing the green pigment *chlorophyll* use sunlight to convert water and carbon dioxide into the food (sugars and starches) and oxygen needed by most other organisms. Satellites can measure the amount of chlorophyll contained in single-celled plants in the ocean's surface layer, from which we can estimate primary productivity.

autotroph — ("self-feeder") organism that makes its own food rather than consuming other organisms.

heterotroph — ("other-feeder") organism that consumes other organisms.

Food chains (Figure 2 below) and more complex food webs (Figure 3 below) illustrate feeding relationships among organisms in biological communities. At the base of food chains and webs are *autotrophs*, which produce their own food for growth and reproduction through photosynthesis. In the ocean, the primary autotrophs are phytoplankton, microscopic single-celled plants that drift near the ocean surface. The remaining organisms in food webs are *heterotrophs*, which obtain food by feeding on other organisms.

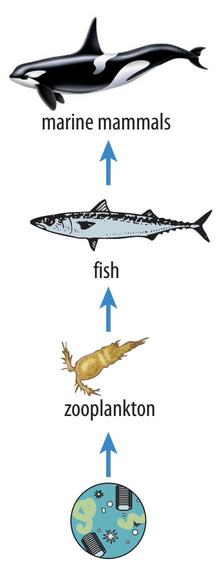


Figure 2. Simple marine food chain. Arrows represent the transfer of energy from one organism to another through consumption.

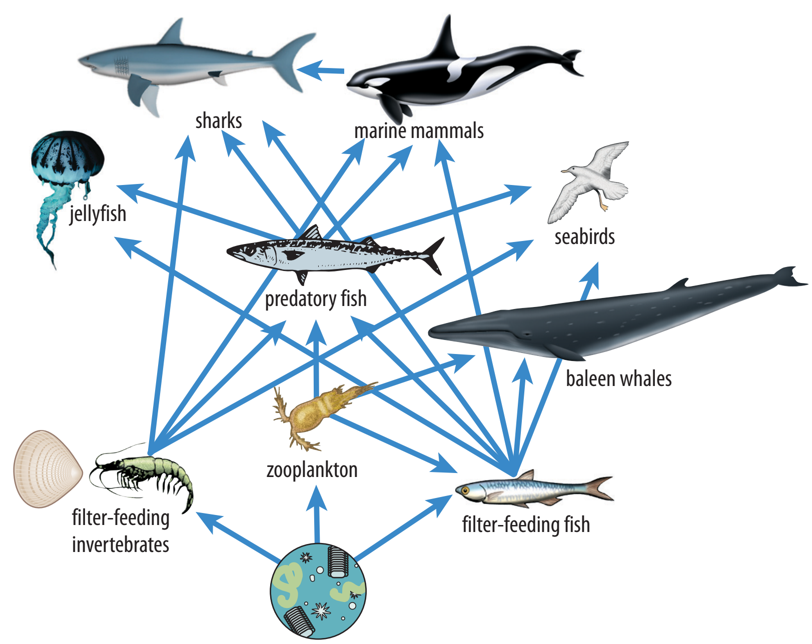


Figure 3. A marine food web.

biotic community — group of interdependent organisms inhabiting the same region and interacting with one another.

anchovies — a type of small fish, similar to sardines, that eat zooplankton.

tuna — a type of large predatory fish that eat other fish.

The preservation of each link in a food web is critical for maintaining diverse and healthy *biotic communities*. However, certain organisms are more critical than others.

1. Examine the complex marine food web in Figure 3 on the previous page. Add anchovies (**A**), tuna (**T**), and humans (**H**) where you think they fit best. Draw arrows as needed to show consumption of and by other organisms.

2. What do you think would happen if all of the autotrophs were removed from the marine food web?

3. What do you think would happen if one of the heterotrophs, such as the predatory fish, were removed?

4. How do humans influence food webs?

respiration — process by which organisms oxidize or "burn" food, producing water and carbon dioxide.

nutrients — chemical compounds that are used by bacteria and plants as the building blocks for organic material. Common nutrients include:

- phosphates (PO_4^-)
- nitrates (NO_3^-)
- silica (SiO_4^-)
- iron (Fe^{3+})

Photosynthesis requires four key ingredients: water, sunlight, nutrients, and carbon dioxide. For marine autotrophs like phytoplankton, there is plenty of water available in the oceans. Carbon dioxide is also abundant in ocean waters. It is released as a by-product of *respiration*, and it is readily absorbed into the ocean from the atmosphere. Thus, water and carbon dioxide are not limiting resources for photosynthesis or primary productivity in the ocean. However, marine productivity is controlled or limited by the availability of the other two necessary resources — sunlight and nutrients.

5. How do you think the availability of limiting resources might vary in the ocean? (Where or when would they be high or low?)

6. Considering the availability of limiting resources, where would you expect phytoplankton to be most productive or least productive? (Near the equator or near the poles? Near the coast or in the open ocean?)

7. How is the productivity of autotrophs important to society? Describe three different ways in which a severe decrease in primary productivity would affect society.

   a.

   b.

   c.

Investigation 4.2

The life-giving ocean

Phytoplankton are tiny—several of them could fit side-by-side across the width of a human hair—but collectively, they pack a wallop. Phytoplankton are *primary producers*, serving as the first link in almost every food chain in the ocean. They transform water and carbon dioxide into carbohydrates, which they use for producing energy for growth and reproduction. Phytoplankton, in turn, are food for other organisms, passing carbohydrates and other nutrients up the food chain. Because phytoplankton release oxygen during photosynthesis, they also play a significant role in maintaining the proper balance of Earth's atmospheric gases. Phytoplankton produce about half of the world's oxygen and, in doing so, remove large amounts of carbon dioxide from the atmosphere.

Given the central role of phytoplankton in stabilizing the mixture of gases in Earth's atmosphere and in providing food for other organisms, it is important to monitor their location and rate of productivity. Although it is impossible to directly measure the productivity of phytoplankton on a global scale, there are several ways of making indirect calculations. One method relies on the distinctive way that chlorophyll, the green pigment in phytoplankton and other plants, reflects sunlight. By using satellites to measure the chlorophyll concentration of the ocean surface layer, scientists can estimate the rate at which phytoplankton produce carbohydrates (Figure 1). Because carbon is the key element in the process, productivity is measured in terms of kilograms of carbon converted per square meter of ocean surface (kgC/m^2) per year.

Photosynthesis

The general chemical equation for photosynthesis is:

$$\underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water}}{6\,H_2O} \xrightarrow{\text{sunlight}} \underset{\text{glucose (carbohydrate)}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\,O_2}$$

NASA

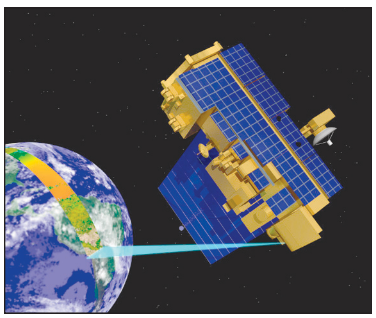


Figure 1. The MODIS (MODerate-resolution Imaging Spectrometer) instrument on the Terra satellite is the latest tool for measuring primary productivity from space.

primary productivity — the rate at which new organic material is formed by photosynthesis.

Global primary productivity

In this exercise you will examine global *primary productivity* and its relation to the factors that support phytoplankton growth.

- Launch ArcMap, and locate and open the **etoe_unit_4.mxd** file.

Refer to the tear-out Quick Reference Sheet located in the Introduction to this module for GIS definitions and instructions on how to perform tasks.

- In the Table of Contents, right-click the **Primary Productivity** data frame and choose Activate.
- Expand the **Primary Productivity** data frame.

This data frame shows the average annual primary productivity for terrestrial and marine environments. During their respective winters, regions near the north and south poles receive little or no sunlight, making satellite measurements impossible. Nonetheless it is reasonable to assume that, with no sunlight, winter primary productivity in these regions is essentially zero.

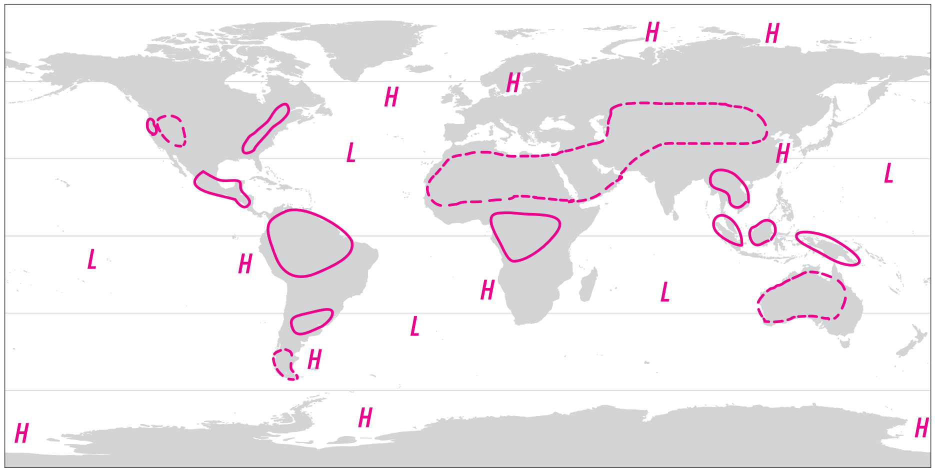
1. What colors represent areas of highest and lowest productivity?

   a. Highest

   b. Lowest

2. On Map 1, see land areas with the highest productivity using solid lines, and the land areas with the lowest productivity using dashed lines.

Map 1 — Areas of highest and lowest productivity



- Turn off the **Terrestrial Productivity** layer.
- Using the Zoom In tool, examine, in detail, the areas with the highest marine productivity.
- When you are finished, click the Full Extent button to zoom back out to show the entire map.

3. Mark the ocean areas with highest productivity on Map 1 using the label **H** (high), and the ocean areas of lowest productivity using the label **L** (low).

4. Where is marine productivity generally

   a. highest?

   b. lowest?

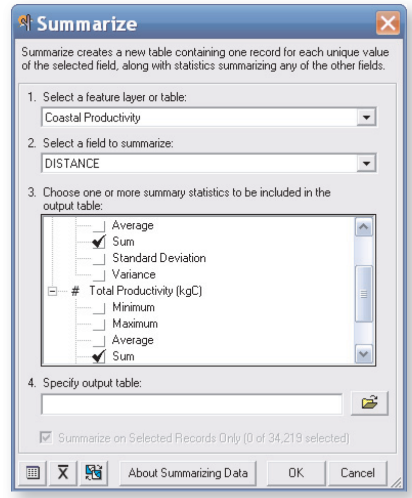
5. Compare the locations of regions of high terrestrial and marine productivity on Map 1. Describe any geographic patterns or similarities in their distribution.

Productivity and distance from coast

Next, you will examine productivity near the coastline in greater detail.

- Turn off the **Marine Productivity** layer.

- Turn on and expand the **Coastal Productivity** layer.
- Click the Summarize button **Σ**.
- In the Summarize window, select **Coastal Productivity** as the **feature layer**.
- Select **Distance** as the **field to summarize** in the drop-down menu.
- Double-click **Area (m^2)** to display the statistics options, check **Sum.**
- Next, double-click **Total Productivity (kgC)** to display the statistics options, check **Sum,** and click **OK**. (Be patient—summary tables may take a while to process.)



In the resulting summary table, the **Sum TOTAL_Prod** field gives the total productivity, and the **Sum_PROJECTED** field gives the total area, for each coastal zone. These values are very large, in the trillions. One trillion is the word for the number value 1,000,000,000,000.

Converting to trillions

Move the decimal point 12 places to the left, then round to the appropriate decimal place.

Example:

27656585301787.3

= 27.7 trillion

6. Record the total productivity and total area for each coastal zone in Table 1. Round productivity and area to the nearest 0.1 trillion. (See sidebar for help with converting values to trillions.)

Table 1 — Marine productivity with distance from coastline

Coastal zone	Total productivity *trillion kgC*	Total area *trillion m²*	Average productivity *kgC/ m²*
Open Ocean (> 960 km)			
Far (640 – 960 km)			
Mid (320 – 640 km)			
Near (0 – 320 km)			

Calculating average productivity

To calculate average productivity, divide the Total Productivity by the Total Area. Be sure to write both measurements in trillions, so the trillions will cancel each other.

Example:

$$\frac{\text{Total Productivity}}{\text{Total Area}} = \frac{27.7 \text{ ~~trillion~~ kgC}}{211.0 \text{ ~~trillion~~ m}^2}$$

= 0.13 kgC/m²

7. Calculate the average marine productivity for each zone and record your results in Table 1. Round to the nearest 0.01 kgC/m². (See sidebar for help calculating average productivity.)

8. What happens to the level of marine productivity as the distance seaward from the coastline increases?

9. Of the resources necessary for photosynthesis (water, sunlight, carbon dioxide, and nutrients), which do you think is most likely to change with distance from the coast to produce the pattern you observe in Table 1? Explain your answer.

- Close the Summary Table window.

nutrients — chemical compounds that are used by bacteria and plants as the building blocks for organic material. Common nutrients include:

- phosphates (PO_4^-)
- nitrates (NO_3^-)
- silica (SiO_4^-)
- iron (Fe^{3+})

Micromoles

Micromolarity is a measure of concentration used to describe very weak solutions. The metric prefix *micro* represents one millionth. A *mole* is 6.02×10^{23} molecules (or atoms), so a micromole is one millionth of a mole, or 6.02×10^{17} molecules. That seems like a lot, but when dissolved in a liter of water (55.5 moles, or about 3.34×10^{25} water molecules) it's only one molecule of nutrient for every 200 million water molecules. That's a weak solution.

Latitude bands

Low latitudes

0° – 30° N and S
near equator

Middle latitudes

30° – 60° N and S
between equator and poles

High latitudes

60° – 90° N and S
near poles

Understanding the patterns

In this section, you will determine when and where sunlight and nutrients control marine productivity. You will examine nitrates and phosphates, but other *nutrients* like silica and iron affect productivity in similar ways.

- Turn off and collapse the **Coastal Productivity** layer.
- Turn on the **Marine Nutrients** layer group.
- Turn on and expand the **Nitrates** layer.

Nitrates and phosphates are important nutrients that are used by autotrophs for building complex molecules needed for growth and development. The **Nitrates** layer displays the average annual level of nitrates in the world's oceans in terms of *micromolarity*, or millionths of a mole of nitrate per liter of seawater (see sidebar).

10. Which latitude bands have the highest and lowest concentrations of nitrates? (See *Latitude bands* sidebar for help.)

    a. Highest.

    b. Lowest.

- Turn off and collapse the **Nitrates** layer.
- Turn on and expand the **Phosphates** layer.

The **Phosphates** layer shows the average annual concentration of phosphates in the world's oceans in terms of micromolarity.

11. Which latitude bands have the highest and lowest concentration of phosphates?

    a. Highest.

    b. Lowest.

12. Are the patterns for both nutrients similar? If not, how do they differ?

- Turn off and collapse the **Phosphates** layer.
- Turn on the **Solar Radiation Flux** layer.

This layer shows the average annual solar radiation that strikes Earth's surface, in watts per square meter (W/m^2).

- Click the Media Viewer button and open the **Solar Flux Movie**.

This animation shows changes in solar radiation throughout the year. The time of year and the legend appear at the bottom of the image.

- View the movie several times.

Use the **Solar Radiation Flux** layer and the **Solar Flux Movie** to answer the following questions.

13. Near what latitude is the average solar radiation throughout the entire year
    a. highest?
    b. lowest?
14. How does the pattern of nutrient concentration you noted in questions 10 and 11 compare to the pattern of solar radiation? Explain your answer.

- Close the Media Viewer window.
- Click the Media Viewer button, and open the **Productivity Movie**.

This animation shows marine productivity throughout the year. The time of year is indicated at the top of the image, and the legend appears at the bottom. Black areas at high latitudes are where there was no sunlight during the winter; you may assume these areas have zero productivity.

- Study the movie to examine how productivity changes throughout the year. Focus on only the extreme high and low levels of productivity. You will need to play the movie several times to fill in Table 2.

15. In Table 2, enter the months and season when productivity is highest and lowest in each hemisphere. (See sidebar for help with the seasons.)

Table 2 — Productivity extremes by hemisphere

Hemisphere	Months of high productivity	Season	Months of low productivity	Season
Northern				
Southern				

- Close the Media Viewer window.

There is very little seasonal variability in nutrients in the high-latitude oceans because the *thermocline* or temperature gradient between shallow and deep water is small, due to low solar-radiation input. This allows free circulation between deep nutrient-rich water and shallow nutrient-poor water. The year-round strong solar radiation in equatorial regions creates a strong thermocline (warm shallow water and cold deep water), which inhibits shallow- and deep-water circulation. Equatorial upwelling does bring nutrients to the surface in some areas, but

Earth's Seasons are

- caused by the tilt of Earth's axis.
- opposite in the northern and southern hemispheres.

Dates (typical)	Hemisphere	
	Northern	Southern
Dec 21 – Mar 20	Winter	Summer
Mar 20 – Jun 21	Spring	Fall
Jun 21 – Sep 22	Summer	Winter
Sep 22 – Dec 21	Fall	Spring

nutrient levels are generally low at low latitudes, particularly during the summer when the air is very stable and winds are weak.

16. Discuss the influence that each of the following factors has on productivity at *high* latitudes, and how productivity in high-latitude regions may change with the seasons.

    a. Sunlight

    b. Nutrients

17. Discuss how sunlight and nutrient levels contribute to the productivity pattern at *low* latitudes, and how productivity in that region may change with the seasons.

    a. Sunlight

    b. Nutrients

In the next activity, you will learn more about marine productivity, the sources of marine nutrients, and the processes that bring nutrients to the surface near the coastlines and in the open ocean.

Quit ArcMap and do not save changes.